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Pigeons were trained to peck at blue or amber keys presented simultaneously in discrete trials. In the first experiment, there were seven discrete trials with reinforcement scheduled probabilistically every seventh trial in the reinforcement interval. The key light went off either after two seconds with no response or after a response had been made. There were no contingencies on pecking in the first six post-reinforcement trials, while on the seventh and following trials the reinforcement remained available until a response was emitted on the key with the scheduled reinforcer. The first experiment varied probability of reinforcement and held duration of reinforcement equal. In the second experiment, duration of reinforcement was the variable manipulated, with all other reinforcement variables, including probability of reinforcement presentation, held equal.

There were two purposes of this experiment. The first was to find evidence to support either a more molar law of behavior such as Herrnstein's (1961) matching law or a more molecular law such as Shimp's (1969) maximizing law. Using the schedule variations described, matching was found. Since concurrent VI schedules are the majority of schedules having found this result, the present schedule

is seen to generalize in its results to the same theoretical situations for which the concurrent VI's are used. The second purpose was to see if the same law would be supported if different variables were manipulated. It was found that frequency and amount of reinforcement effected the probability of responding in the same way and were equal in their effect. That is to say, they followed the same law, that of matching. Certain systematic effects were also found at the more molecular level of analysis that the schedule provided. For instance, responding appeared to be very sensitive to the proximity to reinforcement.

EFFECTS OF PROBABILITY AND DURATION OF REINFORCEMENT ON CHOICE BEHAVIOR IN DISCRETE TRIAL INTERVALS

by

Carolyn Dean Stone

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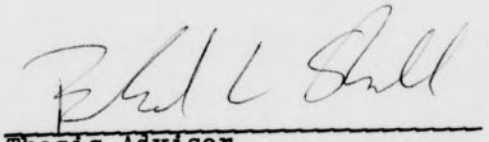

Thesis Adviser

APPROVAL PAGE

This thesis has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Thesis Adviser Rachel L. Shedd

Committee Members D S Waldmann

Carol Brownstein

April 7, 1975
Date of Approval

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CHAPTER I

INTRODUCTION

Concurrent variable-interval variable-interval (concurrent VI VI) schedules of reinforcement provide two or more independently programmed and continuously available variable-interval schedules of reinforcement. One way to program these schedules is called the two-key procedure. It consists of programming each schedule on a separate key. Reinforcements are delivered only for responses on the key assigned to each individual schedule.

Several relations between responding and reinforcement parameters such as frequency of reinforcement and amount of reinforcement have been examined with concurrent VI VI schedules. When the proportion of reinforcements is varied, the proportion of responses made to each schedule often equals or matches the proportion of reinforcements to each schedule (Herrnstein, 1970; Catania, 1963). This relationship, the matching law, can be symbolized by the mathematical formula: $\frac{R_1}{R_1+R_2} = \frac{r_1}{r_1+r_2}$, where R_1 and R_2 are the number of responses emitted on the two keys, and r_1 and r_2 are the number of reinforcements assigned to the two keys.

An important issue involving the matching law is whether the law should be described in molar terms or

whether it is derivable from more momentary, or molecular, processes. "Molar" here means that the animal is sensitive or responsive only to relatively larger, "molar," units of input from his environment. The matching law, as proposed by Herrnstein, says that, given that the animal does respond, the probability of his making a certain response can best be predicted by simply looking at the overall distribution of reinforcements. The probability of his making that response should equal the overall probability of that response being reinforced. A molecular model of responding, in contrast, says that it is possible to break the molar unit down into its smaller components. Shimp (1969), for example, has emphasized the control by the momentary probability of reinforcement for that response. Shimp's model says that of the several possible responses that may or may not produce reinforcement, the experimental animal will choose always to make that response which will more surely produce reinforcement. At any time, then, whichever response has the higher probability of being reinforced should have a probability 1.00 of occurring, or will be the only response made throughout that interval of time. Shimp called his theory "the law of maximization." Actually it is the weighted momentary probability of reinforcement that determines responding. The weighted momentary probability of reinforcement is the momentary probability of reinforcement adjusted for the value of the reinforcer. This would

involve such reinforcement parameters as amount and delay of reinforcement.

Shimp (1969) viewed overall matching on concurrent VI VI schedules (a "molar" relationship) as being a by-product of the tendency to choose the alternative with the higher momentary probability of reinforcement. When momentary probability changes continuously in these schedules, these momentary changes in the reinforcement probability result in matching in the long run. These changes in the momentary probability of reinforcement are due to the fact that the probability of reinforcement on one key will go up purely as a function of time passing while the animal is responding on the other key. Since the momentary probability of reinforcement depends in part on the subject's behavior, and since the probabilities change continuously, it is extremely difficult to track the momentary probabilities in an actual experiment with concurrent VI VI schedules. Determinations of momentary probability values are easier with a concurrent schedule procedure described by Nevin (1969). Nevin's procedure used a two-key discrete-trial schedule. There were a minimum of seven trials per interval. Reinforcement was scheduled on every seventh trial. There were no reinforcements for the first six trials and only one response was allowed per trial. On the seventh trial, reinforcement was made available for a response to either the amber or the

blue key by a probability randomizer set to assign a certain percentage of all reinforcements to amber and a certain percentage to blue. Once a reinforcement was assigned to a color, it remained available until produced and no other assignments were made. This procedure guaranteed that obtained relative frequency of reinforcement (i.e., probability of reinforcement) equaled the scheduled probability of reinforcement, and insured that responding would occur on both keys. At least for the first response in each interval, the key associated with the higher overall probability of reinforcement is also the key with the higher momentary probability of reinforcement.

Given Nevin's procedure, we should at this point note what each of the two models of response prediction discussed would predict for this experiment. Herrnstein's (molar) matching law would predict that the overall proportion of responses on a certain key would equal or "match" the proportion of reinforcements for that key. Hence, his model would predict that if the proportion of reinforcements is 0.75 on the right key and 0.25 on the left key, 0.75 of the responses would be on the right and 0.25 on the left. In addition, for each trial the proportion of responses on a key should equal the overall proportion of reinforcements on that key. Shimp's more molecular law of maximization, in contrast, would predict that the pigeon

would maximize--respond on the key having the highest momentary probability of reinforcement--on every trial.

Nevin's results seemed to strongly support Herrnstein's more molar law of responding. Nevin considered two response probabilities: 1) the probability that the animal will peck on either of the two keys, and 2) the probability that he pecks a certain key, given that he pecks at all. It is this second probability that the two models are concerned with predicting. The probability of pecking either key increased with the trial number--a sort of fixed interval scallop. However, regardless of the trial number, 0.75 of the responses <u>always</u> occurred (on trials 1-7) on the key giving an overall average of 0.75 of the reinforcements.

Before taking his data as a refutation of Shimp's model, however, a closer look should be given to the first response in each of the intervals. The first response after reinforcement, according to Shimp, should always be on the key having the highest momentary probability of reinforcement. Shimp's model would predict, then, that for the trial containing the first response after reinforcement, the probability of responding in that trial should be 1.00 on the right key, which provided 0.75 of the reinforcements, and 0.00 on the left key, which provided 0.25 of the reinforcements. On subsequent trials the analysis becomes more complicated, since the non-reinforcement of a response could provide additional information. Non-reinforcement of a response on the seventh trial is predictive that

reinforcement will be produced by a peck to the alternative key on the next trial. Thus, the schedule provides the opportunity for differentially reinforcing changeovers. The pigeon's ability to discriminate trial number should effect the likelihood of changing over from one key to its alternative. Therefore, given these complications, it is only the first trial on which a peck occurs that may validly be looked at to follow Shimp's predictions. Unfortunately for Shimp's model, Nevin's results yielded a response probability of 0.75 rather than 1.00 for the first response on the key having a 0.75 probability of reinforcement. These results also then seem to fall in line with Herrnstein's molar law, the probability of the post-reinforcement response matching the probability of reinforcement, overall, on the separate keys.

Since Nevin's procedure has analytical advantages, and since it differs in many ways from ordinary concurrent VI VI procedures, it is important to determine the relation between other reinforcement variables and relative responding, such as have been determined with concurrent VI VI schedules. Some of these reinforcement variables are delay of reinforcement and amount of reinforcement.

One independent variable which has been used in the study of behavior is the duration of reinforcement, or the length of time the experimental animal is allowed access to the reinforcer. This is sometimes also called the amount

or magnitude of reinforcement. Catania (1963) showed that when a pigeon's pecking on a single key was reinforced by a variable-interval schedule of reinforcement, the rate of pecking was insensitive to changes in the duration of reinforcement from 3 to 6 seconds. However, when an independent concurrent VI VI schedule was used, the pigeon's responding being reinforced on each of the two keys, the rate of pecking was directly proportional to the duration (i.e., amount) of reinforcement. Thus, a matching relation was found here between relative feeder duration and relative response rate. Other studies also suggested that approximate matching occurs between relative responding and relative feeder duration when the proportion of reinforcements is equal (Neuringer, 1967; Brownstein, 1971).

The present study examined the relation between probability of responding and relative amount of reinforcement using Nevin's procedure. In addition to determining the molar relation between relative responding and relative reinforcement duration, analyses were made to see if lawful relations occur at a more molecular level. The basic prediction from Shimp's (1969) model is that the first response after reinforcement will always be on the key that has the highest <u>weighted</u> momentary probability of reinforcement, or, in the case of this study, would yield the greatest relative total amount of reward. If matching were found instead for the first response after reinforcement, then the molar view

of behavior would be supported. If, however, Shimp's predictions are born out the molecular view of behavior will receive support.

CHAPTER II

METHOD

Subjects

Three male Carnauex pigeons were maintained at 80% of their free-feeding weights. All subjects had previous key-pecking experience on a variety of reinforcement schedules.

Apparatus

A two-key pigeon chamber made by modifying a metal picnic ice-chest was used. White noise masked extraneous sounds. Blue and amber keylights provided the only illumination in the chamber. The experiment was scheduled by standard relay equipment. Data were recorded on counters, an event recorder, and elapsed time meters. Grain reinforcement was used.

Procedure

Initial Training

The subjects were first shaped and then reinforced for each keypeck on one key, then for a keypeck on either the blue or amber key, then only after seven keypecks on either of the two keys. The keylight was initially left on until a peck occurred. After responding was fairly stable the keylight was turned off at the end of a specified

time. This trial time was gradually shortened to 2 seconds. The intertrial interval was gradually increased from 2 seconds to its final value of 6 seconds. The left key remained blue and the right amber throughout training.

Introduction to General Procedure

There were two phases of this experiment. In the first phase the proportion of reinforcers was set at 0.80 for the schedule for one key and 0.20 for the alternative key, and reinforcer duration was the same for both schedules. This was in attempt to replicate Nevin's data. In the second phase, the reinforcement probabilities for the two keys were made equal and the duration of reinforcement was varied for each key for each of five conditions. Total overall amount of reinforcement was held constant over all conditions, as was the total maximum rate of reinforcement.

General Procedure

The subjects were exposed, after initial training, to the following procedure. A trial began with illumination of both keys, one blue (left) and one amber (right). A peck on either key turned off both keylights for an intertrial interval of 6 seconds. If no peck occurred within 2 seconds, the keys were darkened for 6 seconds. Pecks on dark keys extended the intertrial interval for 6 seconds following the peck. On every seventh trial reinforcement was made available for a response to one of the keys.

A probability randomizer was set to assign a percentage of reinforcements to each of the keys. Once a reinforcement was assigned to a color, it remained available until produced; no other assignments were made at this point. This procedure, then, guaranteed that the animal obtained reinforcements at a relative frequency which equaled the scheduled probability of reinforcement, and insured responding on both keys. No reinforcements were ever scheduled for the first six trials following reinforcement, and pecks during those trials in no way influenced the schedule.

In the first phase of the experiment, responses on the amber key were reinforced randomly with an overall probability of reinforcement of 0.20 on the amber key, and a 0.80 probability of reinforcement on the blue key. Reinforcement duration was 4 seconds for both keys. In the second phase, 0.50 of all reinforcements were assigned randomly to each key for each condition. Durations were varied for each condition. Reinforcement duration was 4 seconds, 2 seconds, 6 seconds, 2 seconds, and 1 second, respectively on the left (blue) key and 4 seconds, 6 seconds, 2 seconds, 6 seconds, and 7 seconds, on the right (amber) key, respectively for conditions 1, 2, 3, 4, and 5.

Sessions lasted until 51 reinforcements were obtained by each subject. The sessions were run daily if the birds were within 15 g of their 80% free-feeding weights. An

exception was made for bird G-8, which at one point lost considerable weight.

Table 1 shows the actual sequence of conditions and the number of sessions studied in each condition.

Table 1

	Conditions	Prob. of Reinf. L	Prob. of Reinf. R	Duration(sec) L	Duration(sec) R	Sessions
Phase I	Replication	0.80	0.20	4	4	36
Phase II	1	0.50	0.50	4	4	32
	2	0.50	0.50	2	6	33
	3	0.50	0.50	6	2	28
	4	0.50	0.50	2	6	25
	5	0.50	0.50	1	7	21

CHAPTER III

RESULTS

Two different types of conditions were studied, one varying the reinforcement probability with reinforcement durations equal, and the other varying the reinforcement duration with reinforcement probability equal for the two schedules. The same data were recorded and analyses performed on each. Results for both types of conditions will first be described at a more molar level of analysis, and then at a more molecular level. The results are based on data from the last five days of each condition.

Major results at the more molar level of analysis

Figure 1 shows a log log graph of the ratio of responses on a key as a function of the ratio of the reinforcement assess obtained on that key for each of six different reinforcement conditions. The 0.20, 0.80 data point was the probability manipulation condition, the others, those of the duration manipulations. The 6_R, 2_L data point is a combination of conditions 2 and 4, since the values of all variables were the same for these two conditions.

The matching relation can be stated mathematically as $R_R/R_L=r_R/r_L$, where R_R and R_L are the number of responses to the right and left keys respectively, and r_R and r_L are

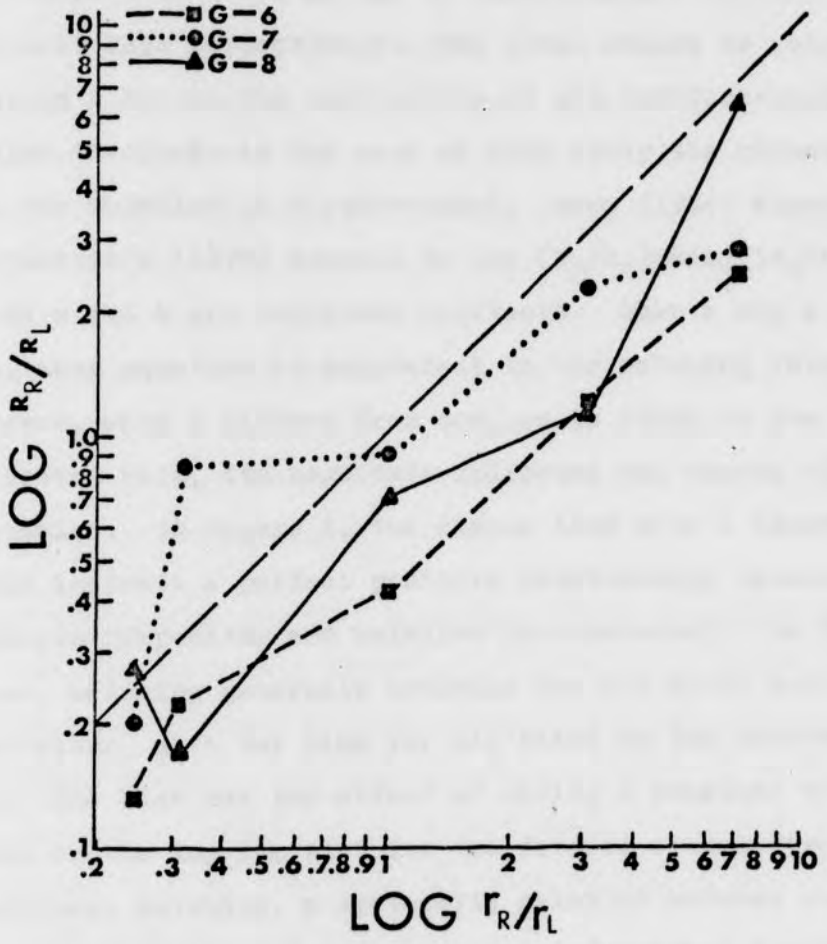

Figure 1. Ratio of responding per ratio of reinforcement. This is a graph of the ratio of responses, log $^{R}R/R_L$, as a function of the ratio of reinforcement obtained, log $^{r}R/r_L$, for each of six different reinforcement conditions. For the 0.25 reinforcement condition the durations were equal and the probability unequal. For the other conditions the probabilities were equal and the duration varied. A slope of 1, the light dashed line, indicates perfect matching between relative responding and relative reinforcement. These functions are based on the last 5 sessions of each condition.

the amounts of total access to reinforcement for the right and left keys respectively. The total access to reinforcement on a key is the combination of all reinforcement variables involved--in the case of this study the probability and the duration of reinforcement. Baum (1974) expanded Herrnstein's (1970) formula to $\log (R_R/R_L)=a\log (r_R/r_L)+\log k$, where a and k are empirical constants. When a and k equal one, this equation is equivalent to the matching relation. However, when k differs from one, as is found in the case presented here, its magnitude indicates the degree of bias in choice. In Figure 1, the dashed line with a slope of 1 would indicate a perfect positive relationship between relative responding and relative reinforcement. As Figure 1 shows, matching generally occurred for all birds across all conditions, with key bias for all birds on the left-hand key. The bias had the effect of adding a constant to the ratio on the log log plot for the favored alternative. Therefore, matching, a systematic relation between overall response distribution and overall reinforcement inputs, was found to hold here whether the duration of reinforcement or the probability of reinforcement was the variable manipulated. Although perfect matching was not found, as would be indicated by the dashed line, when key bias is taken into account, close to perfect matching is clearly shown.

Since the total amount of reinforcements procured for each session was constant across conditions, the total response output (regardless of key) should approximate being the same for each bird across conditions. Figure 2 shows the total amount of responding for each condition for each bird. The amount of total responding was found by dividing the number of trials containing a response (regardless of key) by the total number of trials. Trial seven was not included in this analysis. Although the functions are not perfectly flat, there were no obvious consistent systematic trends.

Major results at the more molecular level of analysis

It was seen that there was a systematic relation between overall response distribution and overall reinforcement inputs. The task undertaken now will be to look for systematic relations at a more molecular level of analysis. Again, data from the last 5 days of each condition were used for all analyses.

Results from replication phase

In the first phase of the present study Nevin's procedure was replicated using a reinforcement probability of 0.80 for the left key and 0.20 for the right. Figure 3 shows the probability of responding and the probability of pecking the blue key, given a response occurred, for each ordinal trial number after reinforcement for each bird. The probability of responding is the probability of making

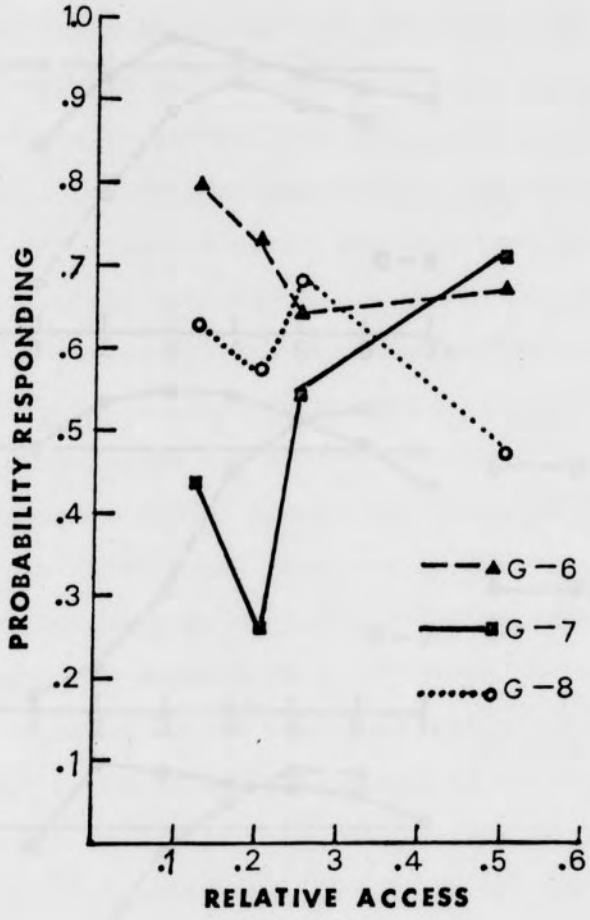

Figure 2. Overall probability of responding per condition. This reflects the total amount of responding across conditions for each bird. Conditions 2, 3, and 4 are combined due to common reinforcement values. These functions were based on the means from the last 5 sessions of each condition.

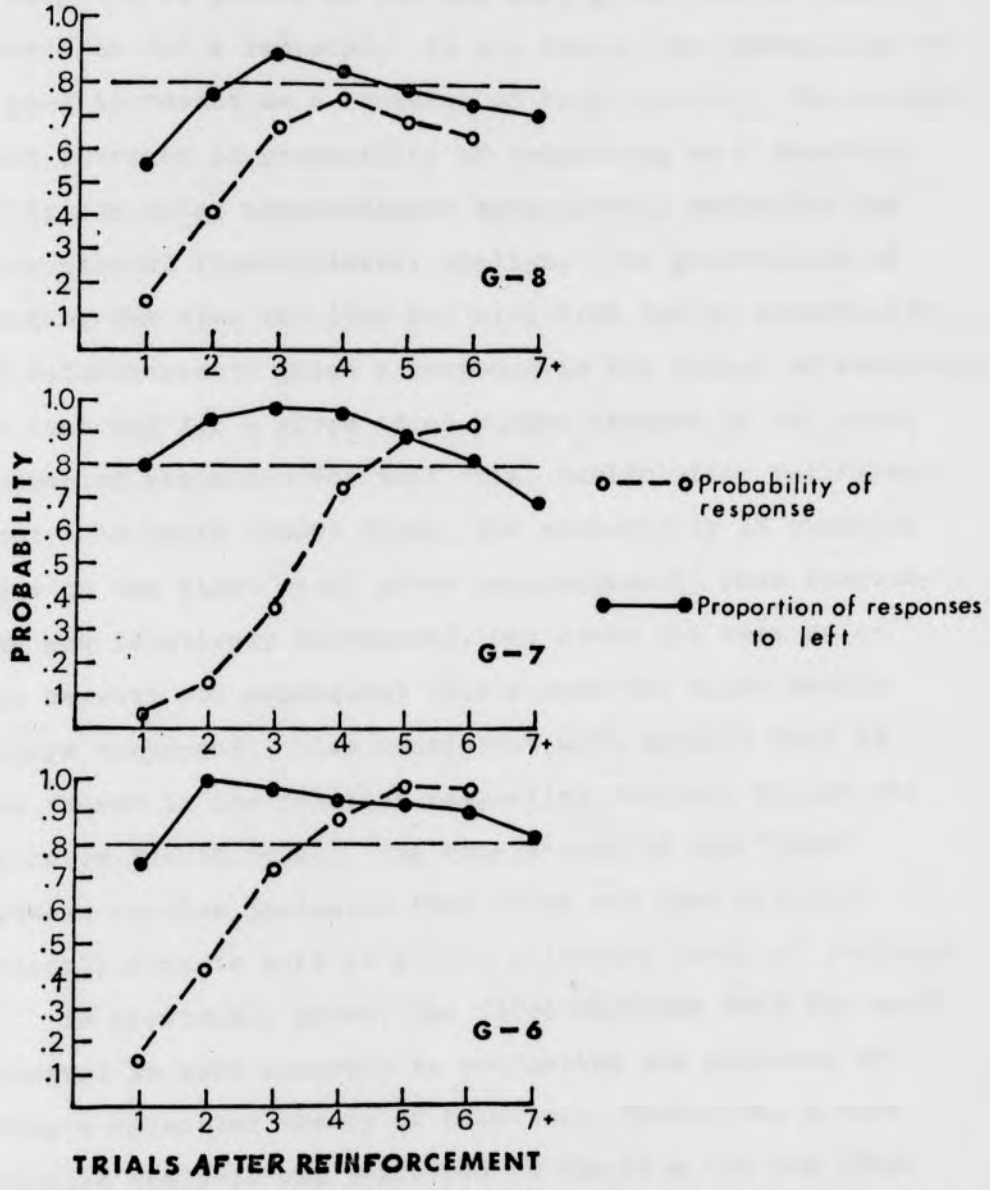

Figure 3. The probability of responding and choice probabilities per trial: probability manipulation. This reflects the probability of responding and the probability of pecking the blue key given a response, as a function of ordinal trial number after reinforcement for each bird. The light dashed line at 0.80 indicates the scheduled relative frequency of reinforcement for the left.

a response on either of the two keys given that a trial is available for a response. In all cases, the probability of a peck increased as a function of trial number. The consistent increase in probability of responding as a function of trials after reinforcement very closely resembles the conventional fixed-interval scallop. The probability of pecking the blue key (the key with 0.80 random probability of reinforcement) given a response is the number of responses on that key for a given trial number divided by the total number of responses for that trial number after reinforcement. As Nevin (1969) found, the probability of choosing blue on the first trial after reinforcement, when responding was relatively infrequent, was about the same as on the seventh and subsequent trials when the birds nearly always responded. Also consistent with Nevin's data is the "hump" in the relative responding function around the third or fourth trial. The consistency of the "hump" between studies indicates that there are some definite schedule effects here at a more molecular level of analysis.

As previously noted, the first response data for each interval is most relevant to evaluating the adequacy of Shimp's molecular theory of behavior. Therefore, a more detailed analysis was performed on the data for the first response after reinforcement, regardless of the trial number on which it occurred. The results of this analysis is summarized in Table 2. The overall probability of pecking blue on the first response after reinforcement was

Table 2

Bird	Preceding Rft.	First Resp. Blue	Amber	Prop. of 1st resp. to blue Pooled	Subdivided	Prop. of total resp. to blue
G-8	Blue	166	37	.815	.830	.796
	Amber	36	9		.800	
G-7	Blue	183	7	.939	.963	.832
	Amber	53	5		.914	
G-6	Blue	190	9	.958	.955	.881
	Amber	47	2		.961	

Table 2. Choices of blue or amber on the first response after reinforcement: probability manipulation. This reflects how the birds chose on their first response after reinforcement, regardless of the trial number on which it occurred, and whether this choice depended on the response previously reinforced. These initial responses had no scheduled consequences, except for the extremely rare instances in which the birds paused for six or more trials after reinforcement. Choices were subdivided according to the immediately preceding reinforcement, during the final 5 of 36 training sessions.

more extreme than the proportion of reinforcements for pecking blue for birds G-6 and G-7. The first peck proportions roughly matched for bird G-8. The last column of the table shows, however, that the distribution of all responses was also more extreme than the distribution of reinforcers. Thus first peck proportions vary directly with overall response proportions. For all birds, the immediately preceding reinforcement had no systematic effect. Thus, the first-peck proportions did not result from a simple perseveration tendency. Nevin (1969) also reported little difference between overall and first-peck proportions and also found little effect of the previous reinforcement.

Further analyses were performed to determine whether the position in the trial sequence of the first peck was related to its probability of occurring on a certain key.

Figure 4 shows the proportion of first responses that occurred on each ordinal trial number after reinforcement, and the probability that these responses were to the blue key. The proportion of first responses is the total of all first responses on a certain trial number after reinforcement divided by the total number of all first responses for all trials combined. The probability of pecking blue is the number of first pecks on blue for a certain ordinal trial number divided by the total number of first pecks for both keys combined for that trial number. The greatest number of first responses occurred around the third trial after

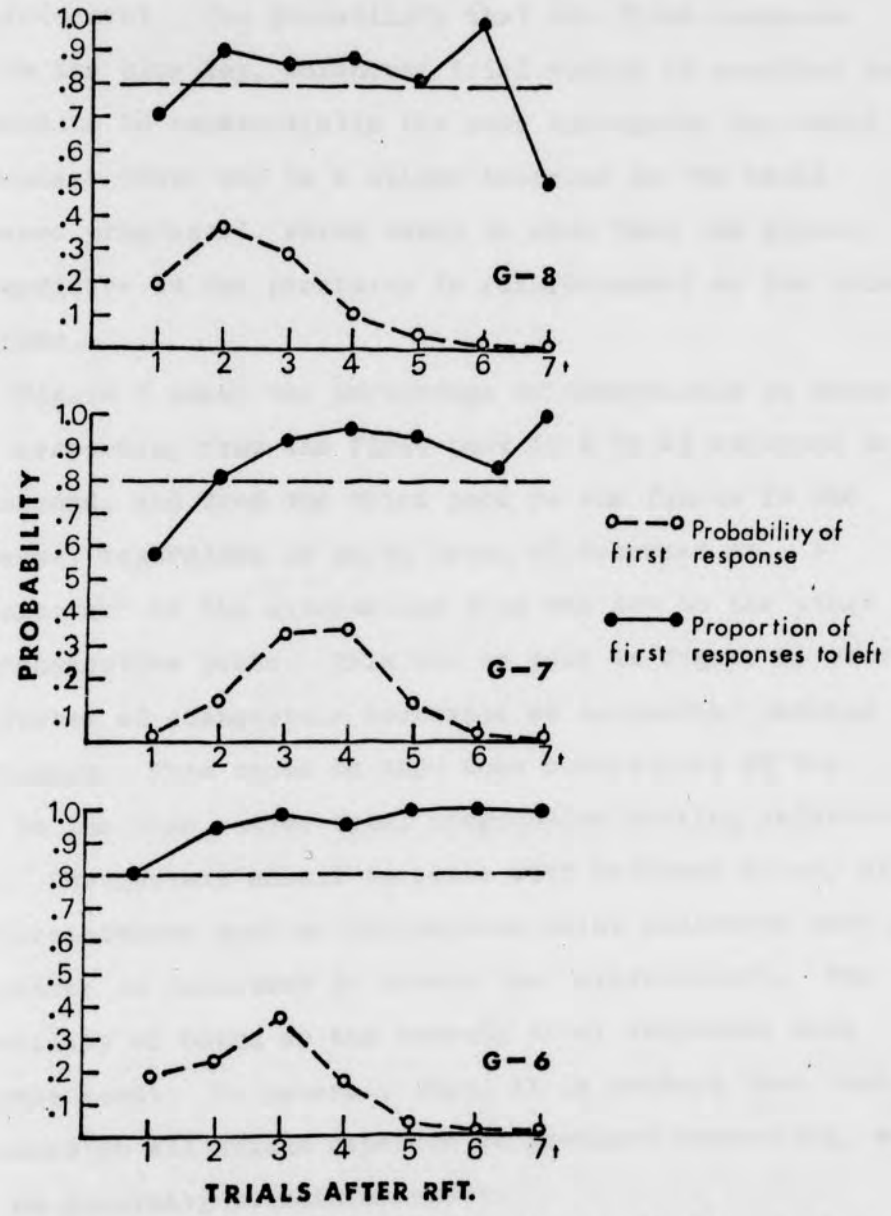

Figure 4. Distribution of first pecks per trial: probability manipulation. This reflects the proportion of first responses that occurred on each ordinal trial number after reinforcement and the probability that these responses were to the blue key. The light dashed line at 0.80 indicates the scheduled relative total access to reinforcement.

reinforcement. The probability that the first response was on the blue key, whichever trial number it occurred on, appears to be substantially the same throughout the trial sequence. There may be a slight increase as the trial sequence progressed, which tends to show that the pigeon is sensitive to the proximity to reinforcement as the trials progress.

Figure 5 shows the percentage of changeovers in sequential responding from the first peck in a trial sequence to the second, and from the third peck to the fourth in the sequence, regardless of which trial it occurred on. A "changeover" is the alternating from one key to the other for two consecutive pecks. This can be seen in Figure 5, where the number of changeovers increased as sequential pecking progressed. This seems to show some sensitivity of the bird to the time and/or trial progression nearing reinforcement. Changeovers should increase with response count, since a non-reinforced peck on the seventh trial indicates that a changeover is necessary to obtain the reinforcement. The probability of being on the seventh trial increases with response count. In general, then, it is evident that choice responses in all trials depended on previous responding, as well as proximity to reinforcement.

Results from the duration manipulation phase

In this phase of the experiment reinforcement probability was held constant at 0.50 for each key, and the

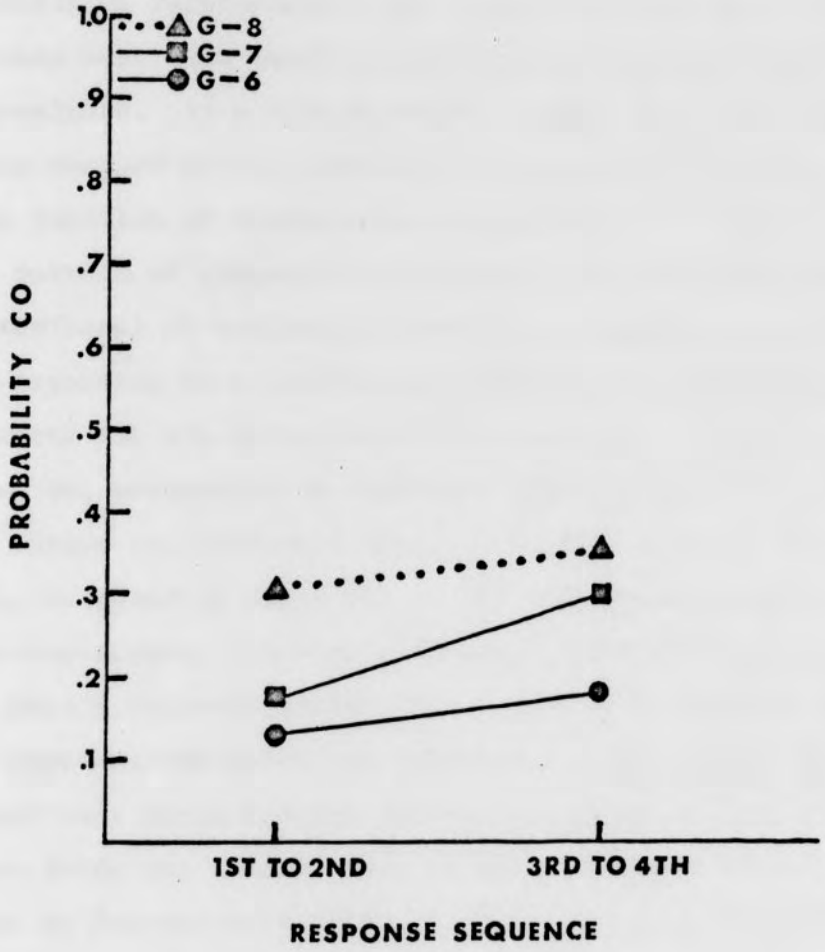

Figure 5. Probability of changeovers in sequential responding: probability manipulation. This reflects the probability of changeovers from the first peck in a trial sequence to the second, and from the third peck to the fourth in the sequence, regardless of which trial it occurred on for the probability manipulation condition. These functions were based on the final 5 of 36 training sessions.

duration of reinforcement was varied for each key. It was already seen that matching was found at the more molar level of analysis. At a more molecular level, there were systematic changes in the overall probability of responding as a function of trials after reinforcement. Figure 6 shows the pattern of responding throughout the trial sequence. A conventional FI scallop, indicating an increased probability of responding as a function of trial number, generally appeared for all birds and all conditions. Figure 6 also shows the proportion of responses made to the key having the longer reinforcement duration on each trial. In general, as found by Nevin and in the replication phase of this experiment, relative responding, with some exceptions, was fairly constant across trials, and this relative responding approximated matching. With only a few exceptions, the "hump" that Nevin and the probability phase of this experiment found can also be seen in these analyses around the third or fourth trial after reinforcement. In the strongest exceptions, conditions 2 and 4, the hump is around the fifth or sixth trial with a decline from the first to about the third trial. From this it appears that choices throughout the trial sequence do depend somewhat on the trial, but possibly in a very complex way. Also, in condition 5, the 7 $sec_{right\ key}$-1 sec_{left} condition, the hump appears even later in the trial sequence to the extent that it appears to be an increasing function. Nevin concluded that his data

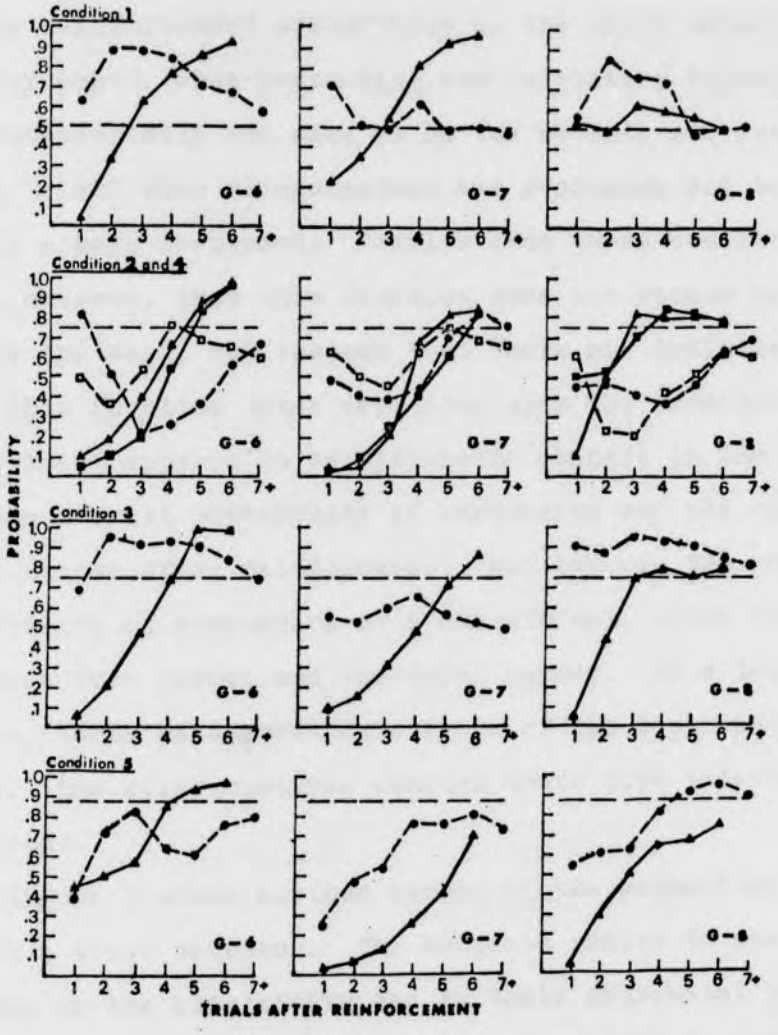

Figure 6. Probability of responding and choice probabilities per trial: duration manipulation. This reflects the probability of responding as a function of trial number, for all birds and all conditions (—▲), also the proportion of responses made to the key having the higher reinforcement value on each trial (--●). Condition 2 is designated by boxes (■). The dashed line in each condition indicates the scheduled relative total access to reinforcement. The functions were based on the final 5 sessions of each condition.

indicated the probability of choosing the key with the higher reinforcement probability on the first trial after reinforcement, when responding was relatively infrequent, was substantially the same as on the seventh and subsequent trials when reinforcement was available and the birds nearly always responded. Results from these conditions show, however, that this function does not remain substantially the same, but instead that there are definite patterns that this function takes depending upon the condition. Therefore, there appears to be systematic changes in the relation between overall probability of responding and the ordinal trial number after reinforcement, and between the conditional probability of responding on a certain key, given that a response does occur, and the trial number. To a large extent, these data approximate those of the replication phase. The molar analyses conceal these more molecular relations.

Figure 7 shows another aspect of the sequential responding in a trial sequence. The subjects tended to change from one key to the alternative one in their sequential responding as the trial length progressed. In condition 3, the condition of 6 sec reinforcement duration on the left or blue key and 2 sec on the right, the same type of data was found as was in the first condition which varied the reinforcement probability. As trial number increased, there was a decrease in stays, and an increase in changeovers, especially

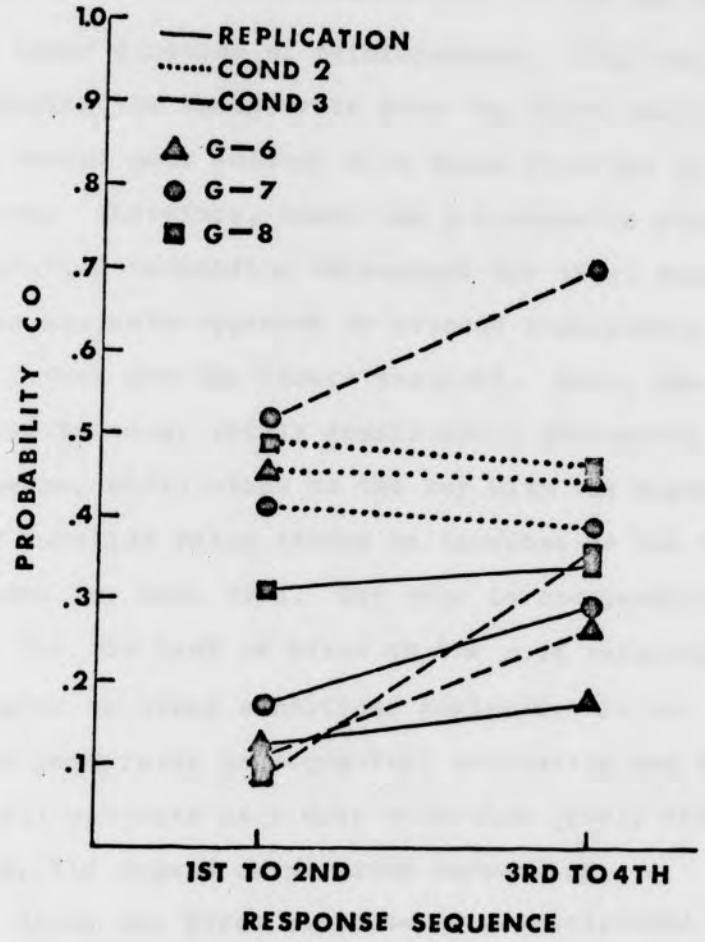

Figure 7. Probability of changeovers in sequential responding: duration manipulation. This reflects the probability of changeovers from the first peck in a trial sequence to the second and from the third peck to the fourth for 3 conditions. The figure indicates whether the birds tended to change from one key to the alternative one in their sequential responding as the response count progressed. These functions were based on the final 5 sessions of each condition.

from the higher reinforcement key to the one scheduled for the lower duration of reinforcement. This can be seen by comparing the changeovers from the first peck emitted to the second peck emitted with those from the third to the fourth. Therefore, there was a systematic relation in the sequential responding throughout the trial sequence. All three subjects appeared to respond differently for condition 2 than for the others analyzed. Here, changeovers seemed to occur fairly consistently throughout the trial sequence, while stays on the key with the higher reinforcement duration value tended to increase as the trials increased for each bird. Key bias is one possible explanation for the lack of stays on the more reinforced key as compared to other conditions analyzed. In any case, systematic patterning in sequential responding was also found here for all subjects at a more molecular level, and choices, again, did depend on previous responding.

Since the first response is uncomplicated by changeover tendencies, it is valuable to see how the distribution of first pecks varies with reinforcement conditions. Figure 8 shows a log log graph of the ratio of first responses on a key as a function of the ratio of reinforcement obtained on that key for each of six different reinforcement conditions. The 0.20-0.80 data point was the probability manipulation condition, where the following points represent the duration manipulation conditions. The 3.0 data point is a

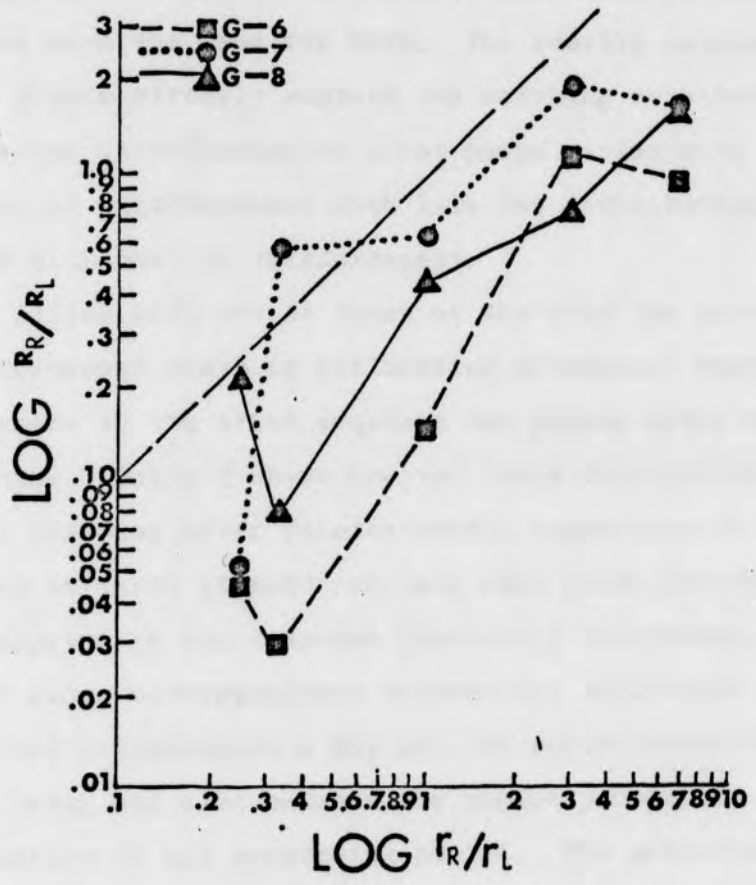

Figure 8. Ratio of first responses per ratio of reinforcement. This is a log log graph of the ratio of first responses, log $^{R}R/R_L$, as a function of the ratio of reinforcement, log $^{r}R/r_L$, for each of six different reinforcement conditions. The 3.0 data point is a combination of conditions 2 and 4. The 0.25 data point indicates the probability manipulation condition. The light dashed line represents the matching function. These functions are based on the last 5 sessions of each condition.

combination of condition 2 and 4, since the reinforcement values were the same for both. The results represented by this figure strongly support the matching relationship, since the distribution of first pecks varies with the distribution of reinforcement much like the distribution of all pecks with that of reinforcement.

A look will now be taken at the role the previous reinforcement plays in influencing subsequent responding and where in the trial sequence the pigeon makes his first response. Table 3 shows how the birds distributed their first response after reinforcement, regardless of the trial number on which it occurred, and also shows how this choice was related to the response previously reinforced. There was a close correspondence between the subdivided proportion of first responses on a key and the pooled proportion for both keys, and also between the pooled proportion and the proportion of all responding pooled. The proportion of the total first responses that occurred in each condition on a particular key depended on the reinforcement access value for that key. The influence of the preceding reinforcement was very slight, in that the position of the immediately preceding reinforcement had only a small effect on the position of the following response. Key bias, it may be noted, is also evident in the results of the first peck data.

Figure 9 shows the percentage of total first responses that occurred on a particular ordinal trial number after

Cond.	Bird	Preceding Rft.	First Resp. Blue	First Resp. Amber	Proportion of Resp's. to Higher Rft. Key Pooled	Proportion of Resp's. to Higher Rft. Key Subdivided	Overall Rel. Resp. to Higher Rft. Key
1 4_L-4_R (0.50)	G-8	Blue	103	41	.693	.715	.588
		Amber	71	35		.670	
	G-7	Blue	85	52	.611	.620	.532
		Amber	68	45		.602	
	G-6	Blue	122	11	.925	.917	.716
		Amber	109	8		.932	
2 2_L-6_R (0.75)	G-8	Blue	89	58	.450	.395	.501
		Amber	51	52		.505	
	G-7	Blue	37	97	.742	.724	.690
		Amber	28	88		.759	
	G-6	Blue	44	91	.672	.674	.625
		Amber	38	77		.670	
3 6_L-2_R (0.75)	G-8	Blue	120	8	.928	.938	.861
		Amber	112	10		.918	
	G-7	Blue	84	43	.636	.661	.542
		Amber	75	48		.610	
	G-6	Blue	126	6	.974	.955	.821
		Amber	117	1		.992	
4 2_L-6_R (0.75)	G-8	Blue	67	54	.417	.446	.561
		Amber	79	50		.388	
	G-7	Blue	59	63	.508	.516	.709
		Amber	64	64		.500	
	G-6	Blue	85	30	.201	.261	.505
		Amber	116	19		.141	
5 1_L-7_R (0.875)	G-8	Blue	46	79	.640	.632	.824
		Amber	44	81		.648	
	G-7	Blue	57	67	.635	.540	.739
		Amber	34	92		.730	
	G-6	Blue	67	58	.488	.464	.707
		Amber	61	64		.512	

Table 3. Choices of blue or amber on the first response after reinforcement: duration manipulation. This reflects how the birds chose on their first response after reinforcement, regardless of the trial number on which it occurred, subdivided according to the immediately preceding reinforcement.

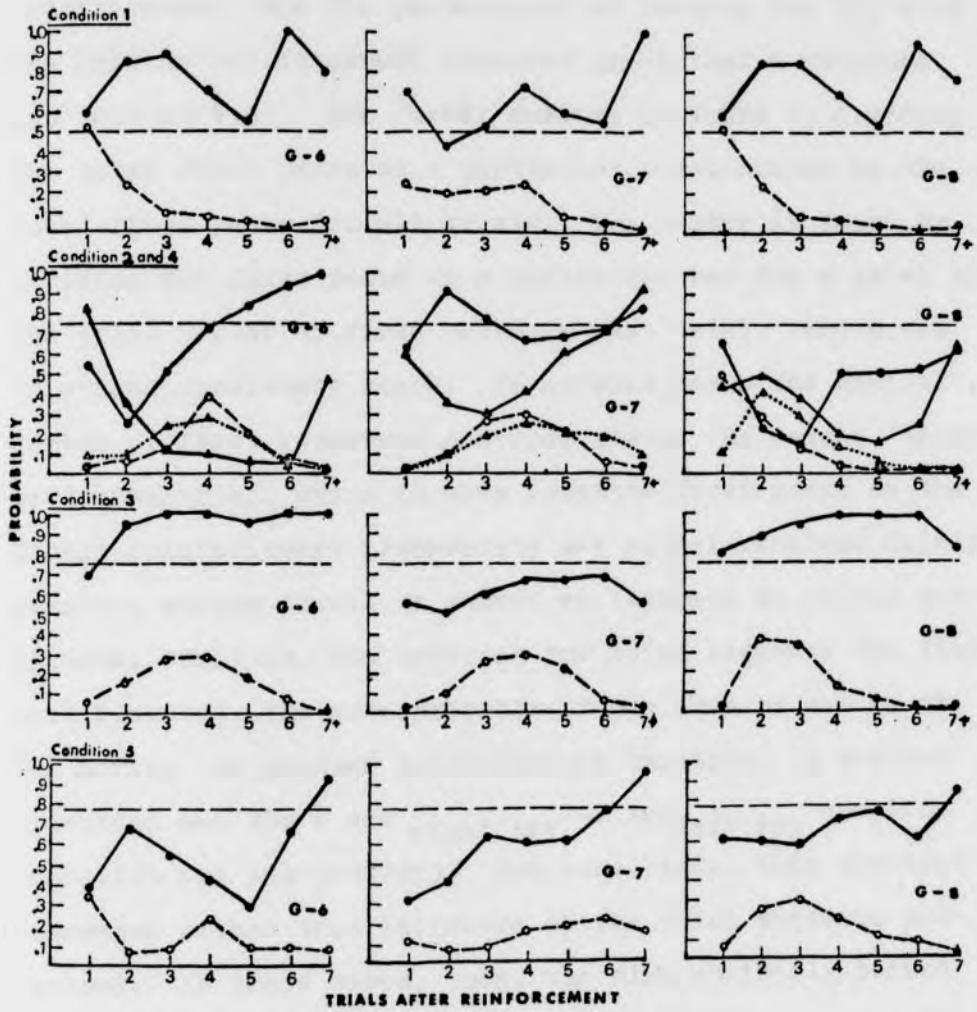

Figure 9. Distribution of first pecks per trial: duration manipulation. This reflects the proportion of a first response on a particular ordinal trial number after reinforcement (--O), and the proportion of pecks to the key with the greater reinforcement duration, given that a response has been made (—O). Condition 2 is designated by triangles (Δ). These functions were based on the final 5 sessions of all conditions in phase II.

reinforcement, and the probability of pecking the key with the greater reinforcement duration given that a response had been emitted. The former measure is found by dividing the total first pecks on a particular trial number by the total first pecks for all trials. The latter is found by dividing the first pecks on a particular key for a trial by the total number of first pecks on that trial. There was no strong consistent trend. In several cases the maximal number of first responses occurred around the second, third, or fourth trial, where in some relative first pecks on the higher reinforcement probability key either remained fairly constant across trials or showed an increase as trials progressed. That is, the later in the trial sequence the first peck occurred, the more probable it was that it was on the key having the greater reinforcement duration. A serious exception was the 6 sec $_{\text{right key}}$--2 sec$_{\text{left key}}$ duration condition and its recovery. For some birds, this function decreased rather than increased as the trial sequence progressed. In these cases, then, the bird obviously pecked more on the least reinforced key as the trial sequence progressed. This may be partially explained by the increased tendency to switch keys in sequential responding as the reinforcement trial is neared. That is, the bird may behave as though he has responded and therefore go to the alternate key. Regardless of the form the patterning takes, however, there appear to be specific patterns of responding for each

condition for all birds. There are, therefore, systematic effects of responding found when looking at the first response distributions at the more molecular level.

CHAPTER IV

DISCUSSION

The major finding of the present experiment was that the overall proportion of responding on a key matched the relative access to reinforcement provided by that key. This was true when reinforcement probability varied with duration equated and also when duration varied with probability of reinforcement equated. These results extended the generality of the matching law to the present schedule. Where Nevin's results extended the generality of the matching law to a discrete-trial procedure, the present study further extended the generality of the matching law for feeder duration manipulation to a discrete-trial procedure. The first phase of this experiment also extended the generality of Nevin's findings.

Previous studies with concurrent VI VI schedules showed matching of response probability to reinforcement probability, feeder duration manipulation, and other reinforcement variables. Catania (1963) found matching between relative rate of responding and the duration of reinforcement using independent concurrent VI-VI schedules (i.e., one in which the pigeon's responding was reinforced on each of the two keys). Neuringer (1967) found matching between choices (choice responses) and duration of reinforcement using a

modified concurrent VI schedule. This relates to the present study in that each response that a pigeon made was, in a sense, a choice, since, hypothetically, it could be the critical one (i.e., the one resulting in reinforcement). It is seen, then, that the finding of a "matching" relation between relative responding and total access to reinforcement has been fairly pervasive using these schedules. Relative rate of responding has been shown by Herrnstein (1961, 1970) to match relative rate of reinforcement using concurrent VI schedules. The relation to this study is that it, too, found an overall matching function. Todorov (1973) points out that similar effects might not occur if probability and duration are both varied together. He shows that the effects may be quantitatively different for the two variables. The present study found the effects to be fairly similar, when varied together.

Given that matching seems to be very general at a molar level of analysis, is there any evidence of control by more momentary (i.e., molecular) variables? The present schedule proved to be very valuable at pinpointing some more molecular effects. One type of momentary effect is that of Shimp's maximizing. The first peck data were examined to see whether the distribution of first pecks followed the maximizing or matching principle. The first response data provided no support for momentary maximizing since the first peck proportions were approximately the same as the

relative overall proportions of responding. Instead, the data were consistent with the matching law (Herrnstein, 1970).

There were, however, momentary effects that would not follow obviously from the matching or maximizing principles. For example, the conditional probability with which the animal would respond on the key with the higher reinforcement probability varied with the trial after reinforcement in the various conditions. The common feature of these patterns for both probability and duration manipulation was a distinctive rise and then fall in the probability of responding on the higher reinforcement key. Nevin reported similar results. This "hump" in the patterning suggests that for the first few trials the animal shows some indifference, then for the "hump" he shows a definite preference for the higher probability key, around the third or fourth trial. As the seventh trial is approached the birds begin to switch back and forth, thereby more nearly approaching a response probability of 0.50. Thus, although the pigeon does not tend to maximize at every point, some tendency to approximate maximizing is seen around this "hump" in the trial sequence. Thus it is seen that the proportion of responses shows control by trial number.

Another more molecular relationship that data from this experiment revealed was that responding appeared to be effected by prior responding: changeover probability

usually increased with response count. This, too, shows a momentary control. The reinforcement condition seems to have a large effect on the amount of changeover responses, especially for the conditions where greater reinforcement value was given to the less preferred key. One reason for this is that bias on a key the animal has grown to prefer for reasons extraneous to the experiment (e.g., strength it takes to peck a key) controls responding more early in the sequence than later in the sequence.

The major conclusion to be drawn from these analyses is that the animal is sensitive to the position or trial in the trial sequence and patterns his responding on a momentary basis. It should also be emphasized that there is a great similarity of behavior effects at the molecular level between the probability manipulation and the duration manipulations. It is unclear, at present, how this lawfulness at the molecular level can account for the consistent relationships (matching) observed at the molar level.

CHAPTER V

SUMMARY

Previous studies using concurrent variable-interval schedules of reinforcement have found that the proportion of responses match the relative total access to reinforcement. The present experiment used a discrete-trial interval reinforcement schedule and also found matching both when varying reinforcement probability and reinforcement duration, the effects of both variables being about the same. Systematic relationships were found also on a more molecular or momentary level of analysis. There was no evidence for a principle of maximizing which, states that any choice response should be to that reinforcement alternative which will more surely produce reinforcement. There were, however, consistent changes in response probability that were not obviously predicted by the matching principle.

The schedule itself proved to be a reliable one and also a very valuable one for looking at more momentary effects. Too, it proved to allow certain analyses due to its simplicity of scheduling and analysis that concurrent variable-interval schedules render impossible.

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